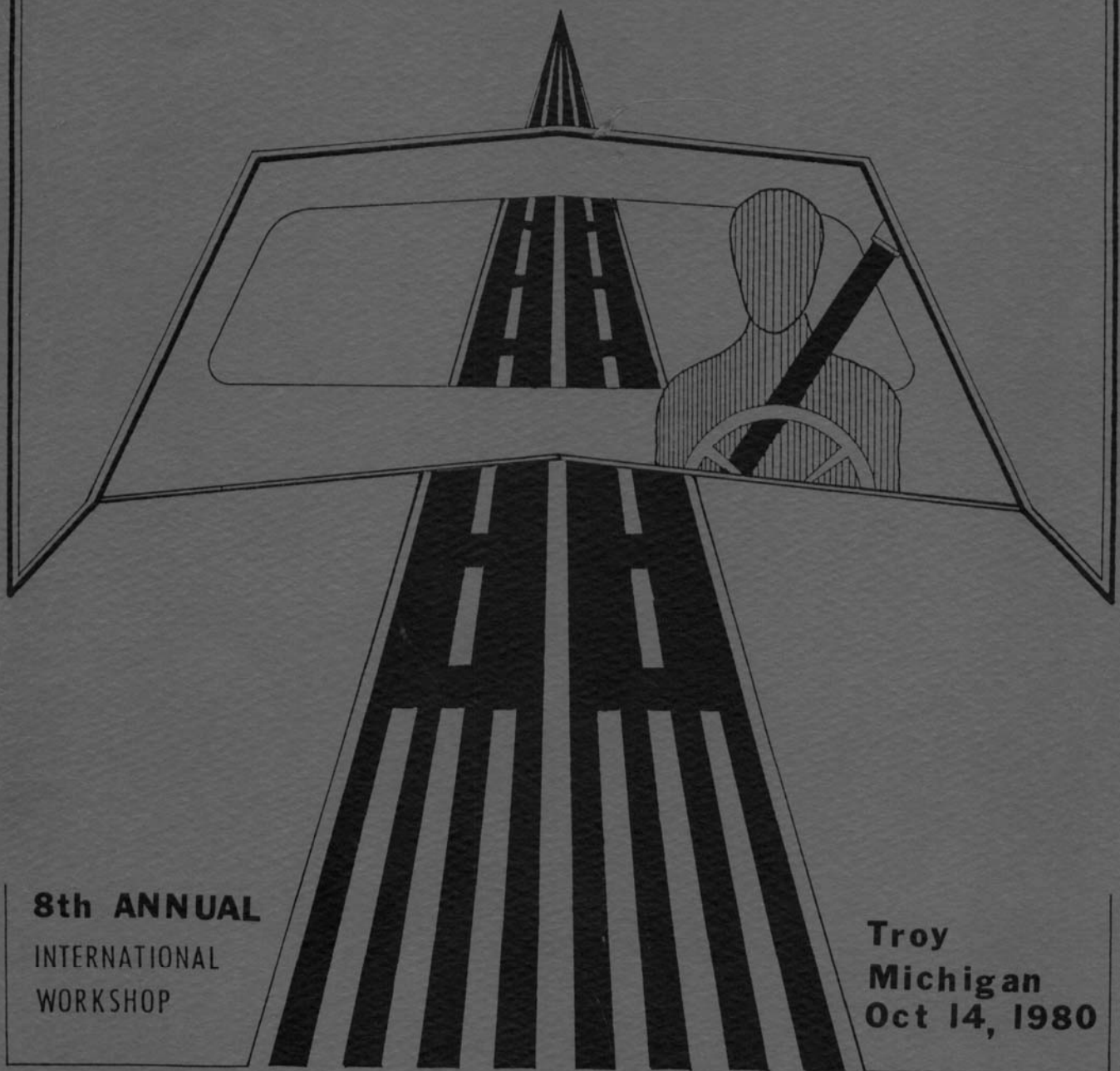


HUMAN SUBJECTS FOR BIOMECHANICAL RESEARCH

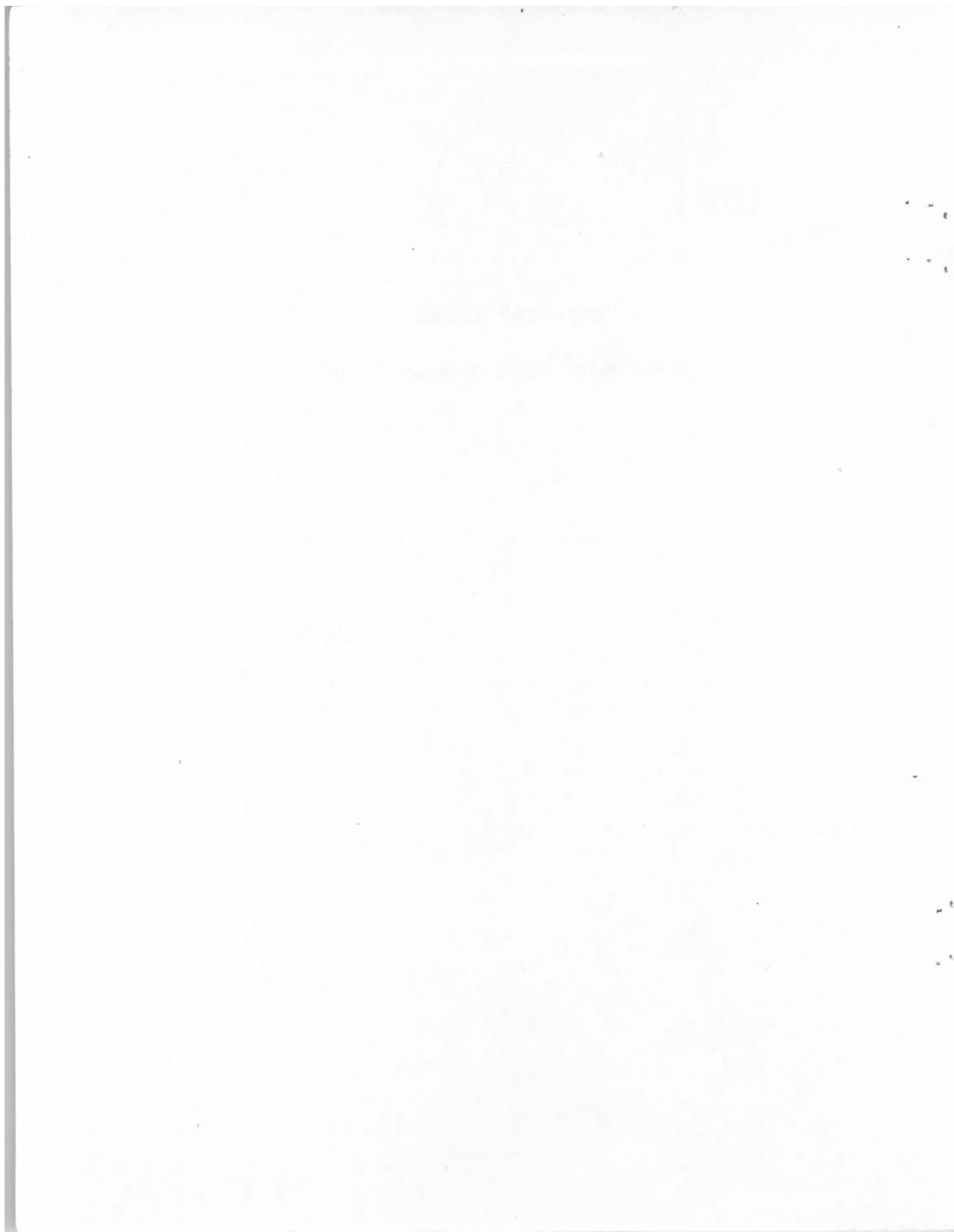


8th ANNUAL
INTERNATIONAL
WORKSHOP

Troy
Michigan
Oct 14, 1980

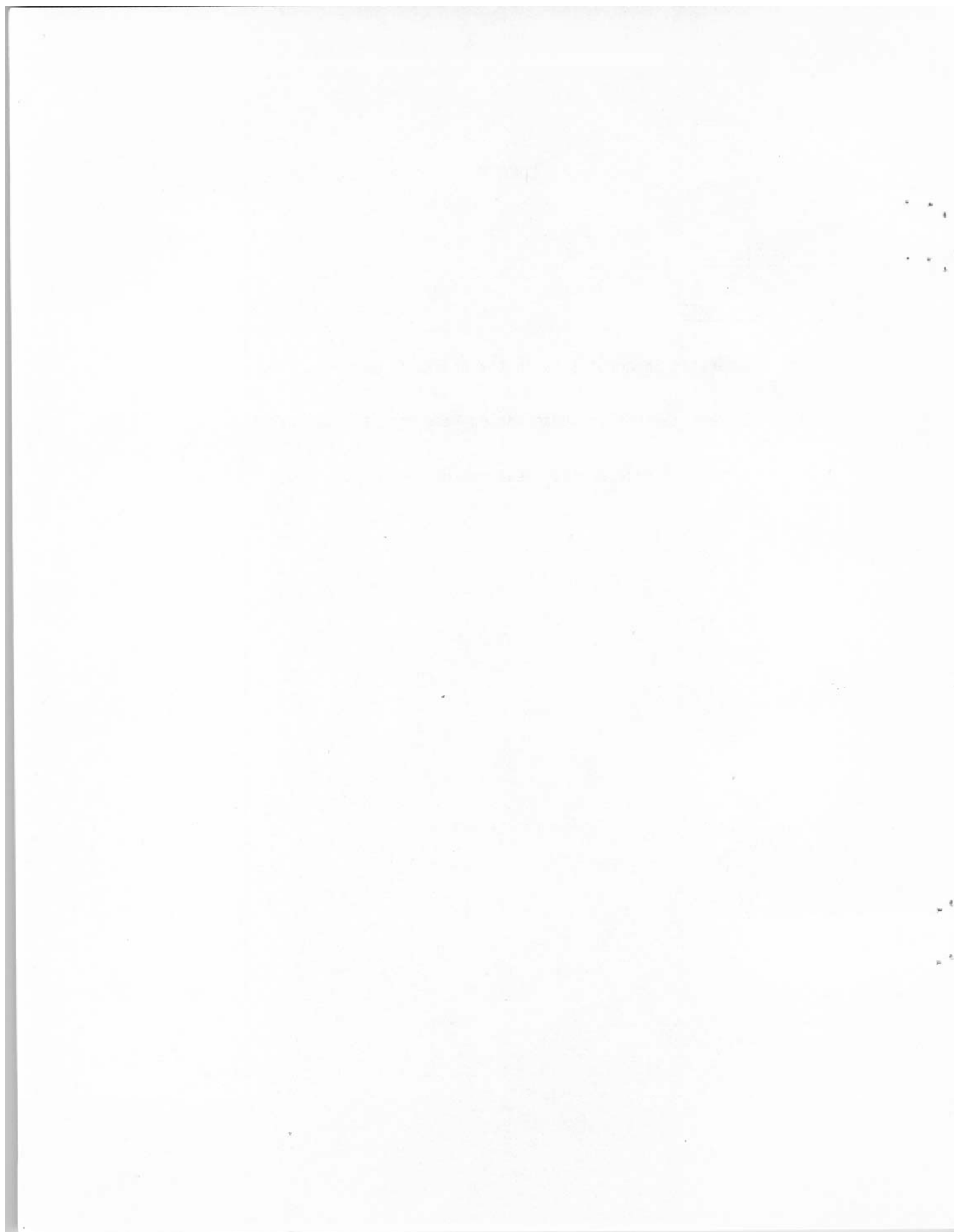
INTERNATIONAL WORKSHOP ON
"HUMAN SUBJECTS FOR BIOMECHANICAL RESEARCH"

- EIGHTH ANNUAL MEETING
OCTOBER 14, 1980
TROY, MICHIGAN



CONTENTS

	<u>Page</u>
<u>MEETING MINUTES</u>	1
<u>TECHNICAL REPORTS</u>	11
Rotation Generated Shear Strains in the Brain, C. Ward	11
Problems of Measurements in Human Analog Research, L. Lustick et al.	31
Progress in Angular Acceleration Measurement, J. Wilson	69



INTRODUCTORY REMARKS

This Eighth Annual Meeting of the Workshop was held at the Northfield Hilton Inn, Troy, Michigan on the day preceding the 24th STAPP Car Crash Conference.

The meeting staff of the Society of Automotive Engineers arranged for the Meeting Room and provided Audiovisual support. The Workshop Committee hereby conveys its appreciation. Refreshments were contributed by Endevco. The committee thanks Endevco for its generosity.

David R. Foust, for the seventh year has acted as recorder. In this particular meeting his minutes have proved invaluable since abstracts of all presentations are included therein. It was not possible to obtain copies of many of the papers.

Arthur E. Hirsch

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EIGHTH INTERNATIONAL WORKSHOP ON
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OCTOBER 14, 1980

NORTHFIELD HILTON INN, TROY, MICHIGAN

MINUTES OF WORKSHOP

The Workshop was convened at 9:30 a.m. by John W. Melvin of the Highway Safety Research Institute (HSRI). More than 50 persons attended the Workshop. In his opening remarks, Dr. Melvin acknowledged the role of Arthur Hirsch of Chi Associates in organizing the Workshop. Dr. Melvin described the nature of the Workshop: it is an informal, ad hoc gathering of researchers in the field of human impact biomechanics and is intended to encourage an open exchange of current information. The published proceedings are not to be cited as a reference.

COMMITTEE REPORTS

1. AD-HOC COMMITTEE ON INJURY & NOMENCLATURE STANDARDIZATION,
R. S. Levine, Wayne State University.

Dr. Levine reported that the committee had held two meetings. The first meeting was devoted to classifying injuries to the lower extremity. Minutes of that meeting were circulated to interested researchers for comment. A final draft of lower extremity injury codes was prepared at the second meeting. This draft is now going through the approval cycle at NHTSA and a coding booklet is expected soon. It is also the committee's goal to develop a code for impairment due to lower extremity injuries, but this objective is not yet complete due to wide variations in impairment among individuals with the same nominal injury. The committee ultimately wants to relate impairment to the Abbreviated Injury Scale.

Mr. Hirsch then commented that the lower extremity coding manual was not yet available from NHTSA, because verification has not been completed. Several physicians are using available injury data from medical records to assign AIS values using the proposed coding method. As this work progresses, it is anticipated that AIS values for lower extremity injuries will be assigned more objectively and consistently.

Mr. Hirsch also anticipates that AIS will be established as a valid predictor of both short and long-term impairment from lower extremity injuries.

In a related comment, Dr. Melvin noted that Dr. T. Gennarelli of U of Pennsylvania presented a paper at the 1980 AAAM Conference in which he reported success in the consistent application of the new AIS 80 to skull and brain injury.

2. ISO ACTIVITY, J. W. Melvin, HSRI

Dr. Melvin reported that he is chairing a working group of the ISO Technical Committee 108 (Mechanical Vibration and Shock) dealing with human impact testing and evaluation. He noted that many of the activities of this International Workshop are pertinent to the ISO activities and that Workshop recommendation may ultimately be formalized through the International Standards Organization. He encouraged Workshop attendees to participate actively in his ISO working group.

TECHNICAL SESSION

1. INJURY INTERPRETATION IN HUMAN ANALOG RESEARCH, D. Thomas Naval Biodynamics Laboratory (NBDL).

Dr. Thomas reported on NBDL research which is developing an injury model for the Rhesus monkey. There is interest in the data for correlation to cadaver test results and human injuries under the same impact conditions. However, the principal objectives of the research are to validate neck injury mechanisms and injury thresholds under controlled conditions not available in epidemiological studies. The injury models are being developed to be applicable to humans.

Twenty-two Rhesus monkeys have been subjected to - G_x acceleration testing since 1976. The NBDL impact sled has been used to produce 10 - 160g impact accelerations, with .2 - .3g coast-to-stop. For each test, the anesthetized subject is in the seated position with the upper torso firmly restrained and the head and neck unobstructed and free to move. Instrumentation includes a six-accelerometer head plate and photographic tracking relative to laboratory reference points. (It is not yet possible to track the head relative to the upper torso because, even with a stiff restraint, upper torso movement cannot be controlled adequately.) Tests with each animal are conducted at 10g increments until an approximate injury threshold is established. Then a 10g control run is conducted, followed by one run at the selected injury-producing level. A detailed neuropathologic exam is conducted post-test.

Dr. Thomas reported some preliminary results. While no firm conclusions are yet possible because of several not-well-defined initial conditions and incomplete modeling of injury factors, there are indications that clear threshold of injury exists. The threshold for "structural failures" in the head-neck system appears to be in the range of 110-120 g's peak acceleration. Above 120g's, all animals received acutely fatal injuries.

Four distinct injury mechanisms have been identified:

a) Atlanto-occipital separation, with loss of ligamentous structures and cord transection (4 cases). No fractures have been observed in the arch, odontoid or articular surfaces;

b) Separation at C1 - C2 (one case);

c) Ring skull fracture, circumferentially around foramen magnum (one case). A pull-out fracture with failure in tension is postulated;

d) Medullary damage without structural failure (one case). No evidence of structural damage was found either radiologically or at necropsy. However, there was much damage to the cervical cord in the medullary area. The injury mechanism was postulated to be motion at the atlanto-occipital junction with bony impingement of the spinal cord.

Dr. Thomas emphasized that all of these injury mechanisms occurred without any direct head impact. This research will continue at NBDL, with extension to other vector directions.

In their comments several other attendees noted their experience with acceleration-related basal skull fractures. Both Dr. Walz and Dr. Tarriere have seen tension-related ring fractures. Dr. Tarriere has seen similar fractures from facial impact.

Dr. Melvin asked about possible correlation between translational head acceleration and injury. L. Lustick of NBDL replied that calculations to determine torque, force and shear had been completed on six animal subjects. Correlation has so far been found with vertical load at the point of head-neck system failure (i.e. along the anatomical Z-axis). The failure threshold was 80 kg for these Rhesus monkeys which had an average mass of 9.1 kg with a head mass of .6 kg.

2. INJURY INTERPRETATION, J. W. Melvin, HSRI.

Dr. Melvin briefly reported on a correlation study of thoracic injury codings using AIS 76 and cadaver thoracic impact test results.

The AIS rating was assigned by HSRI lab personnel, then by several physicians. The ratings were reviewed and compared for differences.

Results showed that both groups assigned similar AIS ratings for skeletal injuries. The greatest variations in ratings were for vascular injuries, especially heart, and lung hemorrhages. While these differences were normally resolved to within one AIS level, the study did point out difficulties encountered in assessing "injury" from cadaver testing.

3. THEORETICAL CONSIDERATIONS OF HUMAN ANALOG USE, C. L. Ewing, Naval Biodynamics Laboratory.

Dr. Ewing presented a theoretical discussion concerning the research uses of human analogs, from the premise that the reason for biomechanical testing with human analogs is to aid in evaluating the effectiveness of protective systems. He noted that test results are often presented in terms of AIS ratings, but he feels that AIS was developed for direct impact injury. As such it may not be adequate to describe the potential injury effects of the "perfect" restraint system which prevents contact and dissipates injury through "indirect impact" between the human and the restraint system. As reported earlier by Dr. Thomas, he is concerned with the head-neck effects of energy dissipation through the torso.

The Naval Biodynamics Laboratory feels that three principal tools are needed to properly evaluate protective systems:

- a) A validated mathematical model of human response to impact;
- b) An anthropomorphic dummy which has true humanlike response in all critical biodynamic parameters and is representative for all humans; and
- c) An injury model to relate the dynamic response of the test "subject" to expected human injury.

Dr. Ewing emphasized the importance of validating the math model and dummy noted above with response data from living humans. While noting that living human responses can be measured under laboratory conditions only to the point of voluntary human tolerance, he cited the NBDL volunteer testing program as being an important source of data to develop response criteria for future human surrogates. He also pointed out that the four types of human analogs are limited to being only analogs since they do not have the same dynamic response as living humans. Finally, he again emphasized the need for adequate international standards in instrumentation systems and anatomical coordinate systems for analog testing, so that dynamic response can be completely determined.

4. ROTATION-GENERATED SHEAR STRAINS IN BRAIN, C. Ward,
Biodynamics/Engineering, Inc.

Dr. Ward reported on shear stress and shear strain studies of brain motion relative to the skull. For these studies, she used the finite element model of a small monkey brain. Model results were correlated with data reported by Dr. Gennarelli at the 22nd and 23rd Stapp Conferences. All studies in the current series were based on head rotation about the anatomical Y-axis (A-P rotation).

Findings related to shear stress: highest stresses occurred in the frontal and occipital areas of the brain. A stress gradient was found in the anterior portion, with the greatest stresses occurring adjacent to the skull. A pressure gradient also develops from the skull inward. In comparisons with Gennarelli, predicted stresses fell within a well-defined range.

Findings related to shear strain: strain occurs in different regions of the brain from stress, primarily on the parietal surface and in the brain stem. Under Y-axis rotation, only X-Z shear strains were observed. A strain gradient develops and the highest strains occur near the surface of the parietal lobe, in the areas which control memory and basic muscular control. The tentorium apparently controls shear patterns.

Dr. Ward drew several conclusions from these studies. There is a preliminary indication that high strain may be related to post-trauma/memory loss. Head rotation has a great effect on shear strain but little effect on intra-brain pressures which relate to contusions. Injuries most likely to result from strain are subdural hematoma and possible concussion.

Dr. Ward answered several questions. Dr. Walz, University of Zurich, has noted bridging vein ruptures at autopsy with bleeding concentrated 1-1 1/2 cm below the brain surface. Dr. Ward replied that her model does not show a strain concentration 1 1/2 cm below the surface. The observed injury may be the result of localized stress concentrations which occur because the brain is not homogeneous and the ventricles carry no load.

Dr. Thomas, NBDL, asked if there are any neuropathology studies of stress/strain injuries. Dr. Ward replied that there are data on stress lesions, but no published strain lesion data.

L. Lustick asked if a simpler lumped mass model has been used for stress/strain studies. Dr. Ward replied that lumped second-order system would be inadequate because of the effects of the foramen magnum. She has, however, used a convolution interval which is simpler than a full finite-element run. The cost of a finite element

model exercise on a commercial computer is about \$50. Dr. R. Eppinger of NHTSA asked about the constitutive properties of the brain which permit separation of stress and strain effects. Dr. Ward indicated that 1) brain material is virtually incompressible, and 2) the small amount of brain motion that exists takes place into the foramen magnum. When asked why high strain was seen without high stress, Dr. Ward replied that her examples were based on different elements in the model and that hydrostatic pressures were low in the elements which reflected the highest strains.

5. PROBLEMS OF MEASUREMENT IN HUMAN ANALOG RESEARCH

L. Lustick, Naval Biodynamics Laboratory.

Mr. Lustick discussed several of the measurement problems being addressed by NBDL in their program to define acceleration response of certain anatomical segments of the body. They have solved many measurement problems by using redundancy - cine-photography, accelerometer arrays and rate gyros.

They have concluded that photography best defines initial rotation, accelerometers are best for determining linear and angular acceleration, and angular velocity can be validated by differentiating photographic data and integrating acceleration data.

Recent work has compared angular velocity derived from photographic analysis, six accelerometer arrays (the system used by NBDL) and nine accelerometer arrays (three triaxial accelerometers). He has concluded that either accelerometer-based technique can lead to calculation problems, and advocates a combination of photography and accelerometer data as the best approach to determining angular velocity.

Mr. Lustick cited three problems related to photographic coverage - digitizing target locations and editing target data, resolving timing mark errors between cameras, and calibrating of camera optics.

He also presented data from the angular velocity study cited above. In general, excellent agreement among the three methods was found for the major axis of rotation, but some departures were noted at the later stages of the pulse for non-major axes. He also notes that accelerometer calibration errors can be masked by a nine-accelerometer system, but become obvious quickly with a six-accelerometer system because the calculations "blow up".

A photographic method which solves for errors in accelerometer orientation and sensitivity constrains the accelerometer data and gives a better match between photographic and accelerometer results. This technique also permits continuous calculation of angular velocity even when photographic targets are temporarily lost.

In answer to a question from Dr. A. King of Wayne State University Mr. Lustick said that NBDL had not used any 3-2-2-2 arrays in their studies with nine accelerometers. He feels the controlling factor in any six or nine accelerometer system is error within the accelerometers.

Dr. A. Hu of New Mexico State University noted that piezoresistive accelerometers are least desirable for human response measurements and that very small and accurate force-balance accelerometers are now available. However, they are also very delicate and very expensive. He suggested it may be appropriate to examine different types of accelerometers for human research. Dr. Melvin agreed and suggested a new ad-hoc committee be established for that topic.

6. TECHNICAL UPDATE ON DEVELOPMENT OF AN ANGULAR ACCELEROMETER, J. Wilson, Endevco.

Mr. Wilson briefly reported on Endevco's development program for a transducer whose output signal is directly proportional to angular acceleration.

An early piezoresistive model under development was found unsuitable for biomechanics research. However, a new prototype angular accelerometer is now being tested. It is small, lightweight and rugged, and it measures angular acceleration from the inertia of a spiral liquid column against a pressure transducer diaphragm. It would be calibrated with an oscillating linear input.

The prototype is not currently suitable for production because of a limited useful frequency range, sensitivity to linear acceleration, and difficulties in manufacturing the device to retain theoretical characteristics. Also, since development and manufacturing costs are high, the potential market is uncertain.

Dr. Hu commented that researchers need better linearity than the 1 - 2% currently achieved by Endevco's prototype.

Mr. Wilson noted that Endevco has wanted to develop a single sensor for each of the six degrees of freedom and place them all in a single package. However, they now doubt the practicality of that approach.

7. EFFECT OF ZERO SHIFT ON CALCULATION OF ANGULAR KINEMATICS,
P. Begeman, Wayne State University.

Mr. Begeman has continued the research he described in the Seventh Workshop. He has been calculating angular velocity using data from Wayne State's 3-2-2-2 nine-accelerometer system. Those calculations have now been extended to actual test data analyzed for 800 msec of pulse.

Late in the pulse, angular velocity and angular rotation calculations contain very large errors, and offset errors are among the most critical because they can cause the calculations to blow up. Offset, and hence offset error, is affected by drift, resolution in analog-to-digital conversion, and zero-level noise.

Better accelerometers may reduce offset errors, but the more practical approach adopted at Wayne State has been to apply a zero shift correction to the data processing. This correction is determined by forcing acceleration at 800 msec to zero, and the technique significantly reduces the error in these calculations. Caution must be used, however, because other errors may make it inappropriate to force acceleration to zero.

The correction is applied only to the overall angular acceleration; it is not possible to isolate on individual accelerometers.

L. Lustick, NBDL, commented that the rotation correction would not work if the head does not return to its exact starting position at the end of the pulse. (He agrees that angular velocity can be forced to zero.) He suggested that the zero shift correction be calculated just prior to the start of the run and be applied throughout the run.

After this discussion, Dr. Melvin appointed a new ad-hoc committee on accelerometers (see closing remarks).

8. SHOULDER MOTION DURING SIDE IMPACT, R. Cheng, Wayne State University.

Dr. Cheng presented kinematic results from a series of -G_y lateral impact studies. Using the Wayne State decelerator sled, cadavers are permitted free ride-down in impacts with rigid walls and with foam padding at shoulder and pelvis. WSU has also obtained acceleration data from a trioxial accelerometer mounted on the shoulder and from the regular head-mounted accelerometers. He noted difficulty in tracking shoulder-mounted targets in these tests - four camera views are necessary for

complete coverage throughout the event. Dr. Cheng is most interested in developing a mechanical analog which accurately represents response between the shoulder and T1.

Photo analysis of rigid-wall impacts show little relative vertical motion, some rotation of T1 relative to the shoulder, and little total body rotation.

Dr. Melvin asked if any skeletal damage had been observed. Dr. Cheng reported, for a "limited" number of tests, one fractured clavicle and as many as four fractured ribs. The results are usually coded AIS 3 for the thorax.

9. STATUS OF SIDE IMPACT STUDIES, C. Tarriere, Association Peugeot-Renault (APR)

Dr. Tarriere reported that APR is continuing accident reconstruction tests of three car-to-car intersection collisions. A film was shown of several tests. To date 30 tests have been conducted, spanning three different impact velocities. Cadavers, Part 572 dummies, and the new APR articulated-shoulder dummy have been test subjects.

Three test results were particularly interesting. In one series, a restrained cadaver remained in the vehicle while an unrestrained cadaver was partially ejected, with the head contacting the hood of the striking vehicle. In another test, three-point belt restraints provided some protection for the rear-side occupant, the first time this event has been observed. In a third test (the most severe at 75 kph impact speed) the near-side driver sustained deceleration-related ligament tear of the liver.

In response to questions, Dr. Tarriere was unsure if shoulder belt loads had been measured and noted that the vascular system was pressurized in cadaver tests but the lungs were not.

Dr. Ewing inquired about shoulder belt loading of the neck. Dr. Tarriere replied that, although there is potential for injury, he has not observed such belt-neck injuries in accident investigations. He believes the side structure of the automobile lessens this injury potential. He would recommend against locating shoulder belt anchorages in the center of the vehicle, since lateral loads would then be applied to an unsupported neck.

CLOSING REMARKS

Dr. Melvin appointed Dr. Anthony Hu, New Mexico State University, as chairman of a new ad-hoc committee on accelerometers. Dr. Hu's committee will plan to report at the next Workshop. Dr. Hu's address is P. O. Box 3-PSL, Las Cruces, New Mexico 88003. Interested attendees were

urged to participate in the ad-hoc committee.

Dr. Melvin then announced that the Ninth International Workshop will be held in conjunction with the 25th Stapp Car Crash Conference in San Francisco, California, during the week of October 28, 1981.

Respectfully submitted,

David R. Foust
Secretariat